Modeling Coastal Ocean Optical Properties for Coupled Circulation and Ecosystem Models

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LONG-TERM GOAL

The overall goal of this work is to develop an extremely fast but accurate radiative transfer model, called EcoLight, for use in coupled physical-biological-optical ecosystem models, and then to use those models for understanding the ocean optical environment.

OBJECTIVES

Currently available ecosystem models often use fairly sophisticated treatments of the physics (e.g., advection and near-surface thermodynamics and mixing) and biology (e.g., primary production and grazing) but use grossly oversimplified treatments of the optics. The optics component of coupled ecosystem models is sometimes just a single equation parameterizing the scalar irradiance or photosynthetically available radiation (PAR) in terms of the chlorophyll concentration. Such simple models often fail even in Case 1 waters, and they can be wrong by orders of magnitude in Case 2 waters. The objective of this year's work was to continue developing a radiative transfer model that can be used in coupled models to bring the optics component up to the level of accuracy and sophistication needed for ecosystem models that are being applied to any water body, including Case 2 waters.

APPROACH

The Hydrolight radiative transfer model (www.hydrolight.info; see also Mobley and Sundman, 2001a,b) provides an accurate solution of the radiative transfer equation (RTE) for any water body, given the absorption and scattering properties of the water body and boundary conditions such as incident sky radiance and bottom reflectance. Unfortunately, the standard version of Hydrolight requires too much computer time to make it suitable for use in ecosystem models where the light field must be computed at many grid points and at time intervals of order one hour. However, ecosystem models require only the scalar irradiance as a function of depth and wavelength, $E_o(z,\lambda)$, which makes it possible to optimize the Hydrolight code to run extremely fast. In particular, because irradiances are computed as azimuthal integrals of the radiance, it is possible to solve the azimuthally integrated RTE to obtain azimuthally averaged radiances, from which the irradiances are easily obtained. Working with the azimuthally integrated RTE removes much of the computation load in Hydrolight, which solves for azimuthally dependent radiances. I therefore tailored the Hydrolight 4.1 code to run as fast as possible with the constraint that the computed $E_o(z,\lambda)$ values at the bottom of the euphotic zone must

Report Documentation Page

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Modeling Coastal Ocean Optical Properties for Coupled Circulation and Ecosystem Models	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Sequoia Scientific, Inc.,,2700 Richards Road, Suite 107,,Bellevue,,WA, 98005**	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The overall goal of this work is to develop an extremely fast but accurate radiative transfer model, called EcoLight, for use in coupled physical-biological-optical ecosystem models, and then to use those models for understanding the ocean optical environment.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

be accurate to ten percent. The resulting highly optimized version of Hydrolight 4.1 is called EcoLight 4.1.

WORK COMPLETED

This year's work continued the development of EcoLight and its merger with the ROMS/EcoSim models (Bissett, *et al.*, 1999), which are being used for ecosystem simulation in the HyCODE program. The EcoLight 4.1 subroutine takes the component concentration profiles generated by EcoSim, converts the concentrations to absorption, scattering, and backscattering coefficients, generates scattering phase functions having the proper backscatter fraction, and uses those IOPs along with sky conditions and other input passed down from ROMS/EcoSim to compute the scalar irradiance as a function of depth and wavelength. EcoLight also computes the nadir-viewing remote-sensing reflectance R_{rs}, which is useful for comparison with hyperspectral imagery of the region being simulated. No other ecosystem light model can predict R_{rs} for prediction validation. Figure 1 shows examples of these EcoLight inputs and outputs for one particular station and time.

Full use of the coupled ROMS-EcoSim-EcoLight ecosystem model is awaiting final code development for the ROMS component. However, we have performed preliminary optical studies in a "post run" fashion, as follows. A lengthy ROMS/EcoSim run had been made previously to simulate the physics and biology of the West Florida Shelf (WFS). That run used the simple optics model originally built into EcoSim to generate the in-water irradiances needed for the phytoplankton primary production calculations. The IOPs as saved from that run were then used as input to the EcoLight 4.1 subroutine to recompute the irradiances and, more importantly, to compute the remote-sensing reflectance R_{rs} corresponding to the ecosystem conditions predicted by the original ROMS/EcoSim run. (The ROMS/EcoSim model as originally formulated cannot predict R_{rs}.) The EcoLight-computed R_{rs} values were then consistent with the IOPs as predicted by the ROMS-EcoSim model using the original optics model. These R_{rs} spectra were then compared with the corresponding SeaWiFS spectra.

RESULTS

The left panel of Fig. 2 shows the WFS study area, which consists of 30 transects from the 10 m isobath to 60 km offshore, with stations at 1 km intervals along each transect. The middle panel of the figure shows the SeaWiFS R_{rs}(443 nm) values for June 8, 1998 for the WFS. The right panel of the figure shows the SeaWiFS R_{rs}(443 nm) values for November 8, 1998, after Tropical Storm Mitch passed over this area. The R_{rs}(443 nm) values are generally higher after the storm, presumably due to resuspended sediments in the water.

Figure 3 compares the ROMS-EcoSim-EcoLight predicted R_{rs}(443 nm) values with the SeaWiFS values, for the average of the 30 transects shown in the left panel of Fig. 2. Before the storm, the water was generally Case I, and the predicted values are in good agreement with SeaWiFS. After the store, the predicted values are much less than the SeaWiFS values. We believe that the post-storm discrepancy can be explained as follows. The storm caused much runoff of both CDOM, which is highly absorbing, and of terrestrial particles, as well as resuspension of sediment particles. The particles are highly scattering. CDOM absorption is accounted for in the ROMS-EcoSim models, so that the predicted post-storm R_{rs} is decreased by the extra CDOM input from the storm. However, the ROMS code does not at present have a sediment resuspension component. Thus the storm-generated suspended sediments are not accounted for in the input given to EcoLight. These particles greatly increase the backscatter in nature and give the increased Rrs values as seen in the SeaWiFS data,

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especially in the shallow water near shore. Thus the predicted R_{rs} values are much too low after the storm. This result highlights the need to include sediment resuspension in the physical model, if accurate simulations are to be made for storm events in shallow waters. Additional comparisons of this type can be found in the related annual report OP08 by P. Bissett.

This year's work has shown that it is computationally feasible and scientifically valuable to perform exact radiative transfer computations within the context of a time- and space-dependent ecosystem predictive model.
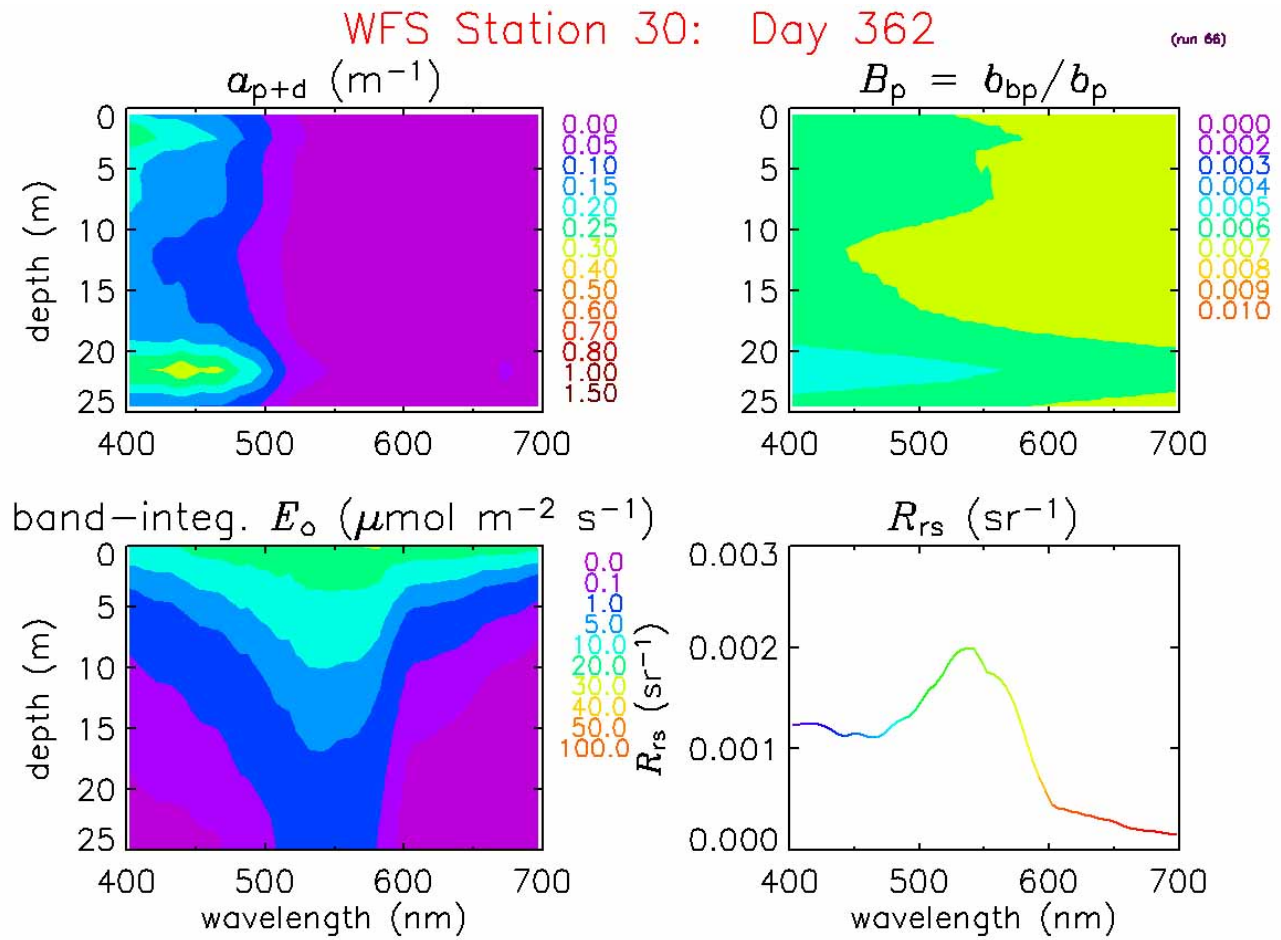

Figure 1. Example input and output for EcoLight for one station and time. The upper left panel is the particulate and dissolved absorption as a function of depth and wavelength. The upper right panel is the particle backscatter fraction, which is used to determine a depth and wavelength dependent scattering phase function. The lower left panel is the computed scalar irradiance, as used by EcoSim. The lower right panel in the remote-sensing reflectance, as used for comparison with SeaWiFS data.
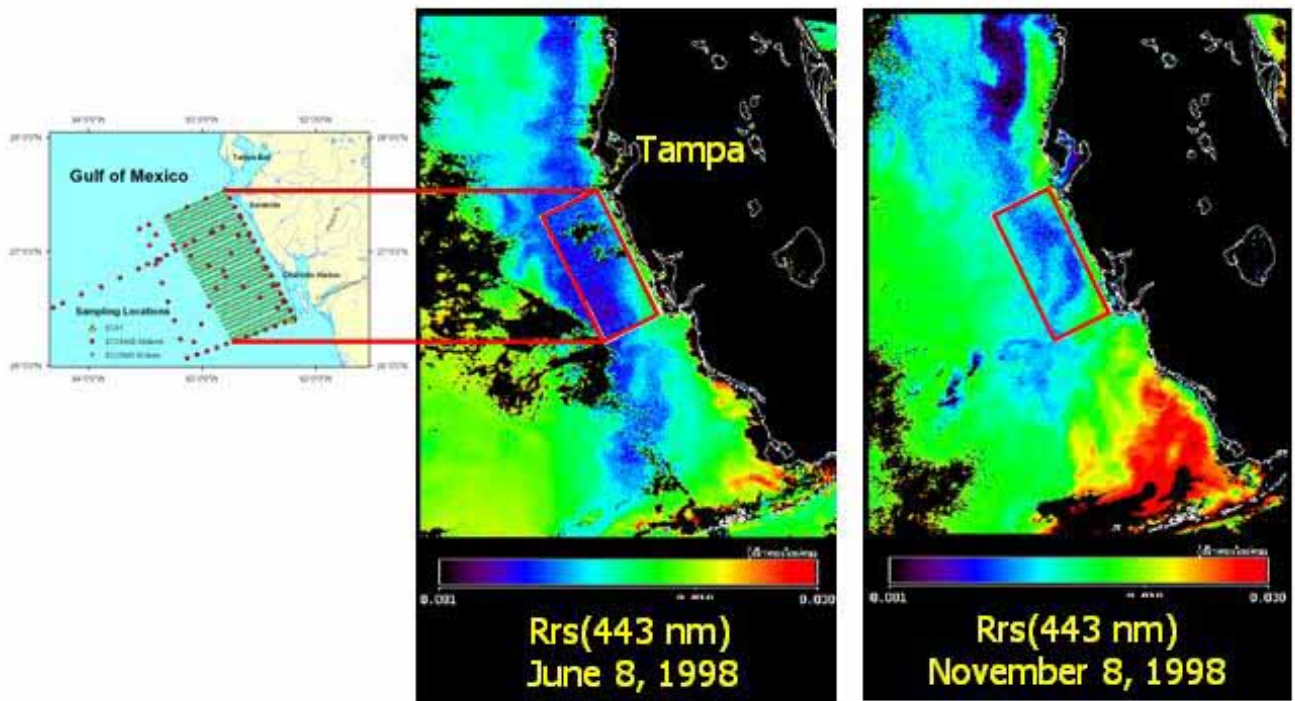*[the figures are color coded by value]*

Figure 2. The West Florida Shelf (WFS) study area and SeaWiFS images before and after Tropical Storm Mitch. Left panel: the 30 transect lines on the WFS study area. Middle panel: SeaWiFS R_{rs} at 443 nm for the WFS on June 8, 1998. Right panel: SeaWiFS R_{rs} at 443 nm for the same area on November 8, 1998, after Tropical Storm Mitch.
[The pictures are color coded to show the value of $R_{rs}(443 \text{ nm})$. After the storm, $R_{rs}(443 \text{ nm})$ is generally higher.]
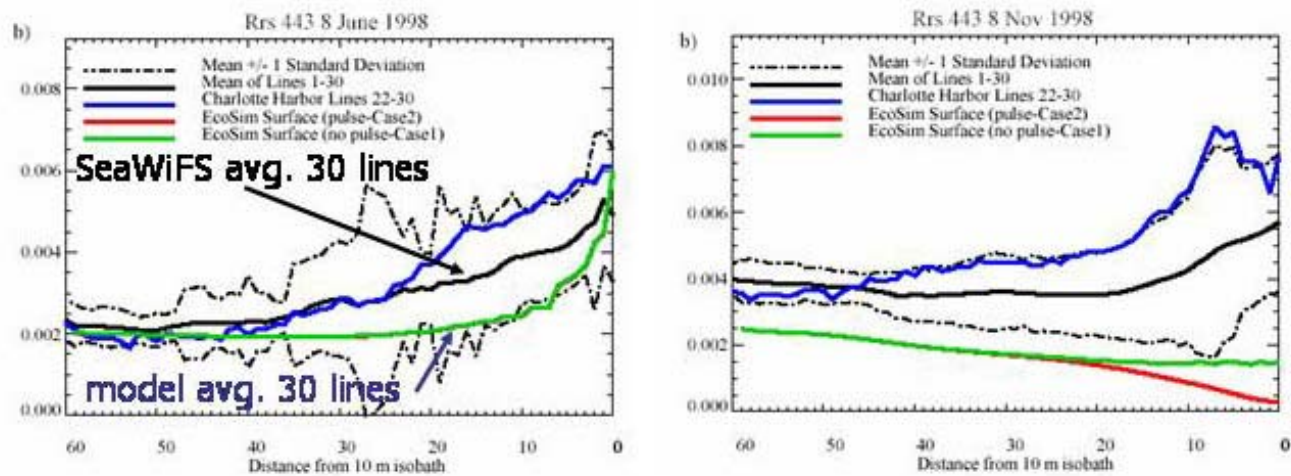

Figure 3. Comparison of predicted (red and green lines) and SeaWiFS (black line) R_{rs} values at 443 nm, before (left panel) and after (right panel) the storm.

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IMPACT/APPLICATION

Predictive ecosystem models are playing an increasingly important role in our understanding of the oceans. Applications of such models range from predictions of water clarity for military purposes to management of coastal waters for fisheries. The incorporation of the EcoLight model developed here into coupled ecosystem models will give improved accuracy in the predictions of primary production and related quantities made by such models. As the coupled models become more trustworthy in their predictions, they will become even more valuable as tools for ocean science.

TRANSITIONS

All versions of the EcoLight code have been delivered to Dr. Paul Bissett, who is using the code in coupled ecosystem models for the West Florida Shelf and the LEO-15 site off the coast of New Jersey. His work is also part of the HyCODE program. The algorithm for dynamic determination of phase functions has been incorporated into Hydrolight version 4.2 and distributed to all Hydrolight users.

RELATED PROJECTS

The coupled ROMS/EcoSim/EcoLight code will next be used in *de novo* simulations for the LEO-15 site. That collaboration with Drs. Paul Bissett of FERI and Hernan Arango of Rutgers University is underway and we expect that this collaboration will continue to be the focus of next year's work.

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Chang, G. C., T. D. Dickey, C. D. Mobley, E. Boss, and W. S. Pegau, 2003. Toward closure of upwelling radiance in coastal waters. *Appl. Optics*, 42(9), 1574-1582 [published, refereed]

HONORS/AWARDS/PRIZES

C. D. Mobley of Sequoia Scientific, Inc. was invited to give the prestigious Riley Memorial Lecture at Dalhousie University (www.dal.ca/~wwwocean/ocean_1093.html) in September 2003. This honor is

conferred each year on a scientist of international reputation by the Oceanography Dept. of Dalhousie University, Halifax, NS, Canada. Mobley discussed some of the EcoSystem simulation work in his presentation.